Chapter 14 - The (wider) organic manufacturing industry

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Plastics and polymers

In 1933, Reginald Gibson and Eric Fawcett carried out a reaction involving ethene and another organic chemical called benzaldehyde (C_6H_5CHO) using a pressure of about 2000 atmospheres. They were hoping to make these two chemicals react to produce another organic substance from a homologous series called ketones. The reaction vessel leaked and some air (oxygen) got in and much more ethene had to be added. Upon opening the reaction vessel they found a white waxy solid instead of what they expected. They subsequently discovered that this solid was in fact a new type of substance. It was found to consist of very large molecules, each one made up of many thousands of ethene molecules (Figure 14.1). 'Many' in Greek is poly, and so the new substance was called 'poly(ethene)' (or polythene). The modern plastics industry was born with this accidental discovery.

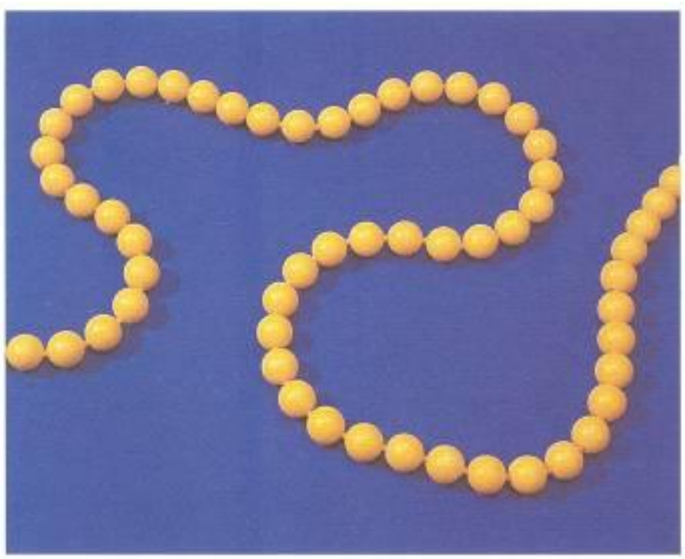


Figure 14.1 Molecules of ethene in this polythene chain are represented by individual poppet beads.

Polythene has many useful properties.

- It is easily moulded.
- It is an excellent electrical insulator.
- It does not corrode.
- It is tough.
- It is not affected by the weather.

- It is durable.

It was first used to insulate telephone cables and its unique electrical properties were essential during the development of radar. Its properties continued to be exploited, and today it can be found as a substitute for natural materials in plastic bags, sandwich boxes, washing-up bowls, wrapping film, milk-bottle crates and squeezy bottles.

We now manufacture polythene by heating ethene to a relatively high temperature under a high pressure in the presence of a catalyst.

where n is a very large number. In polythene the ethene molecules have joined together to form a very long hydrocarbon chain (Figure 14.2). The ethene molecules are able to form chains like this because they possess carbon–carbon double bonds.

Figure 14.2 This model shows part of the polythene (poly(ethene)) polymer chain.

Polythene is produced in three main forms:

- low density polythene (LDPE)
- linear low density polythene (LLDPE)
- high density polythene (HDPE).

The world production of all types of polythene is about 52 million tonnes per year, with the UK producing about 0.64 million tonnes.

Other alkene molecules can also produce substances like polythene; for

example, propene produces polypropene, which is used to make ropes and packaging. When small molecules like ethene join together to form long chains of atoms called **polymers**, the process is called **polymerisation**. The small molecules, like ethene, which join together in this way are called **monomers**. A polymer chain often consists of many thousands of monomer units and in any piece of plastic there will be many millions of polymer chains. Since in this polymerisation process the monomer units add together to form only one product, the polymer, the process is called **addition polymerisation**.

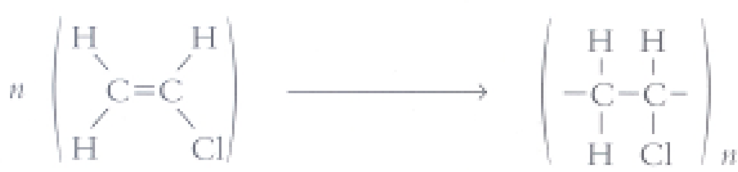
Other addition polymers

Many other addition polymers have been produced. Often the plastics are produced with particular proper-ties in mind, for example PTFE (poly(tetrafluoroethene)) and PVC (polyvinyl chloride or poly(chloro-ethene)). Both of these plastics have monomer units similar to ethene.

PVC monomer (vinyl chloride or chloroethene)

PTFE monomer (tetrafluoroethene)

If we use chloroethene (Figure 14.3a), the polymer we make is slightly stronger and harder than polythene and is particularly good for making pipes for plumbing.

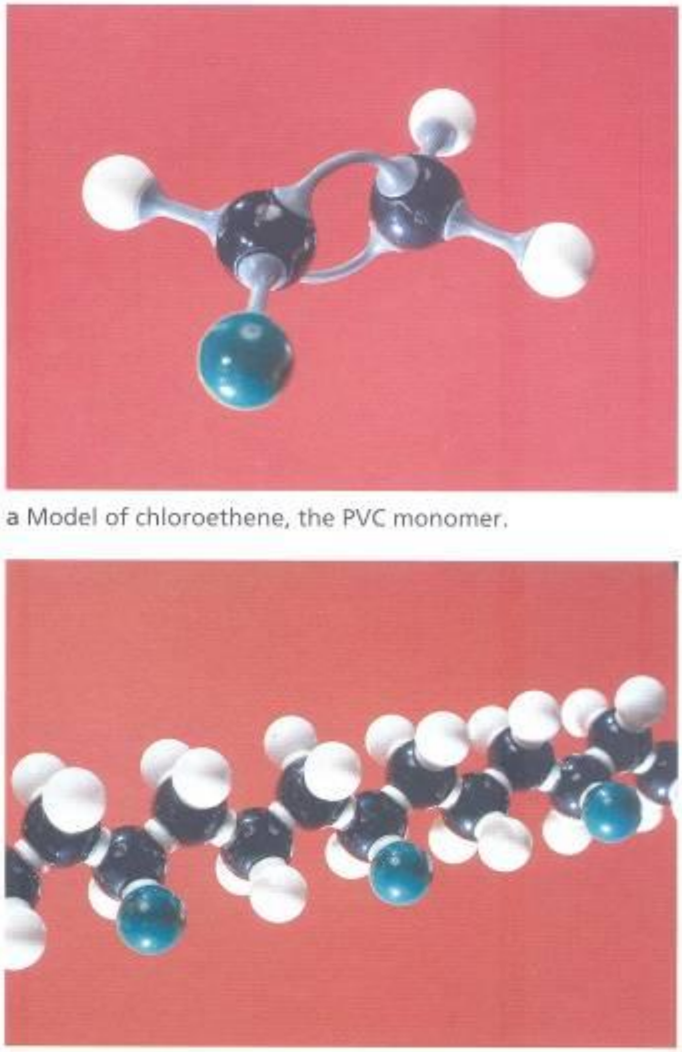


monomer

polymer chain

PVC is the most versatile plastic and is the second most widely used, after polythene. Worldwide 27 million tonnes are produced annually, of which

0.47 million tonnes are produced in the UK.



a Model of chloroethene, the PVC monomer.

b Model of part of a PVC polymer chain.

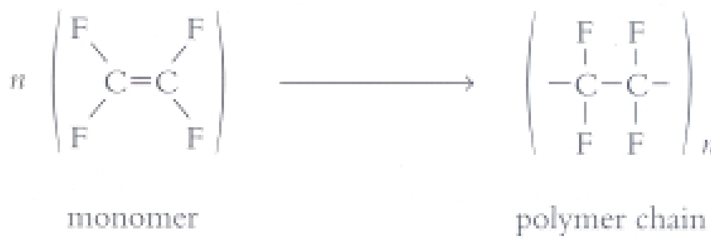
Figure 14.3

If we start from tetrafluoroethene (Figure 14.4a) the polymer we make, PTFE, has some slightly unusual properties:

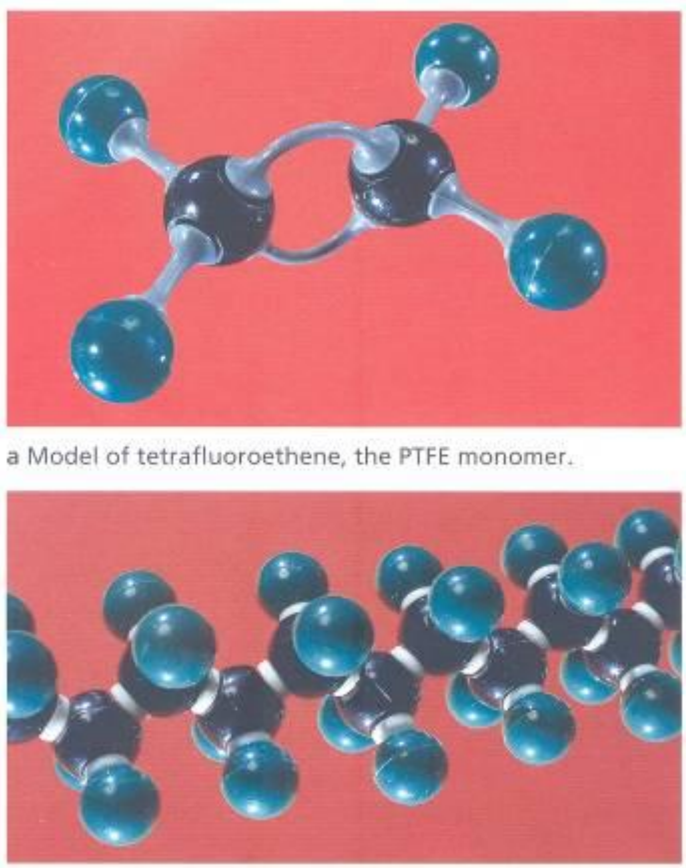
- it will withstand very high temperatures, of up to 260°C
- it forms a very slippery surface
- it is hydrophobic
- it is highly resistant to chemical attack.

These properties make PTFE an ideal 'non-stick' coating for frying pans and saucepans.

Every year 50 000 tonnes of PTFE are made, of which 3000 tonnes are made in the UK.



The properties of some addition polymers along with their uses are given in Table 14.1.



a Model of tetrafluoroethene, the PTFE monomer.

b Model of part of the PTFE polymer chain.

Figure 14.4

Table 14.1 Some addition polymers.

Plastic	**Monomer**	**Properties**	**Uses**

Poly(ethene)	$CH_2=CH_2$	Tough, durable	Carrier bags, bowls buckets, packaging
Poly(propene)	$CH_3CH=CH_2$	Tough, durable	Ropes, packaging
PVC	$CH_2=CHCl$	Strong, hard (less flexible than poly(ethene))	Pipes, electrical insulation, guttering
PTFE	$CF_2=CF_2$	Non-stick surface, withstands high temperatures	Non-stick frying pans, soles of irons
Polystyrene	$CH_2= CHC_6H_5$	Light, poor conductor of heat	Insulation, packaging (especially as foam)
Perspex	$CH_2=C(CO_2CH_3)CH_3$	Transparent	Used as a glass substitute

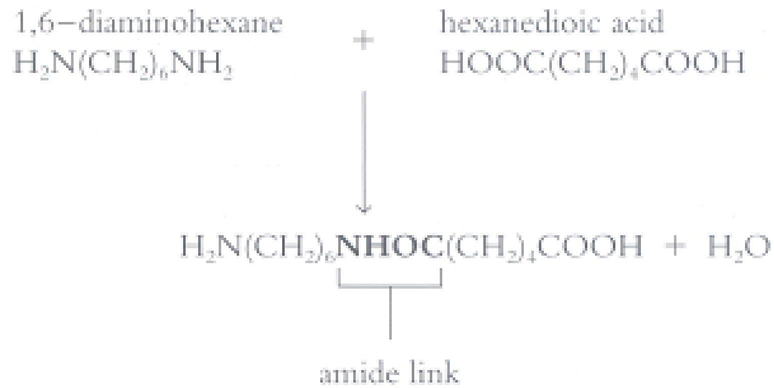
Condensation polymers

Wallace Carothers discovered a different sort of plastic when he developed nylon in 1935. Nylon is made by reacting two different chemicals together, unlike polythene which is made only from monomer units of ethene. Polythene, formed by addition polymerisation, can be represented by:

–A–A–A–A–A–A–A–A–A–A–

where A = monomer.

The starting molecules for nylon are more complicated than those for polythene and are called 1,6-diaminohexane and hexanedioic acid.



The polymer chain is made up from the two starting molecules arranged alternately (Figure 14.5) as these molecules react and therefore link up. Each time a reaction takes place a molecule of water is lost, and because of this it is called **condensation polymerisation**. Because an amide link is formed during the polymerisation, nylon is known as a **polyamide**. This type of polymerisation, in which two kinds of monomer unit react, results in a chain of the type:

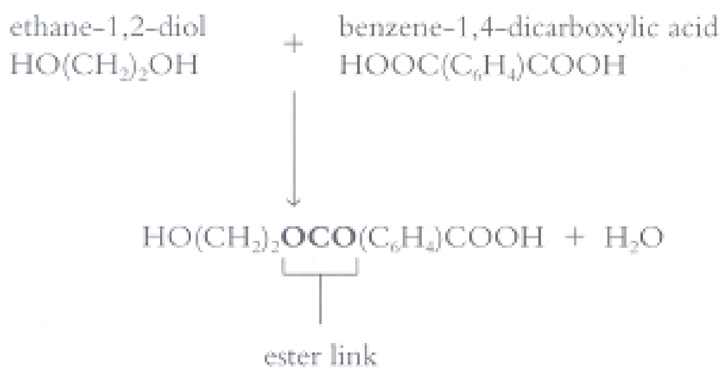
–A–B–A–B–A–B–A–B–A–B–

Figure 14.5 A nylon polymer chain is made up from the two molecules arranged alternately just like the two different coloured poppet beads in the photo.

When nylon is made in industry, it forms as a solid which is melted and

forced through small holes (Figure 4.21). The long filaments cool and solid nylon fibres are produced which are stretched to align the polymer molecules and then dried. The resulting yarn can be woven into fabric to make shirts, ties, sheets and parachutes or turned into ropes or racket strings for tennis and badminton rackets. The worldwide production of nylon is 5.4 million tonnes per year.

We can obtain different polymers with different properties if we carry out condensation polymerisation reactions between other monomer molecules. For example, if we react ethane-1,2-diol with benzene-1,4-dicarboxylic acid, then we produce a polymer called terylene.



Like nylon, terylene can be turned into yarn, which can then be woven. Terylene clothing is generally softer than that made from nylon but both are hard wearing. Because an ester link is formed during the polymerisation, terylene is known as a **polyester**.

Thermosoftening and thermosetting plastics

Plastics can be put into one of two categories. If they melt or soften when heated (like polyethene, PVC and polystyrene) then they are called **thermoplastics** or **thermosoftening plastics**. If they do not soften on heating but only char and decompose on further heating, they are known as **thermosetting plastics**.

Thermoplastics are easily moulded or **formed** into useful articles. Once they are molten they can be injected or blown into moulds, and a variety of different-shaped items can be produced (Figure 14.6). Thermosetting plastics can be heated and moulded only once, usually by compression moulding (Figure 14.7).

Figure 14.8 shows the different molecular structures for thermosetting and thermosoftening plastics. Thermosetting plastics have polymer chains which are linked or bonded to each other to give a **cross-linked** structure, and so the chains are held firmly in place and no softening takes place on heating. Thermosoftening plastics do not have polymer chains joined in this way, so when they are subjected to heat their polymer chains flow over one another and the plastic softens.

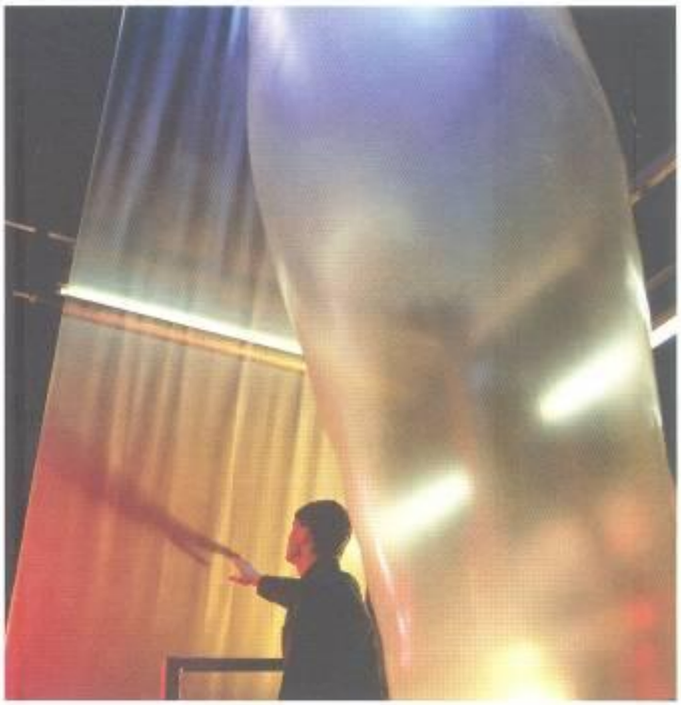


Figure 14.6 Blow moulding in progress in the recycling of polythene.

Figure 14.7 These objects are made from compression-moulded thermosetting plastic.

a In thermosetting plastic the chains are cross-linked.

b In thermosoftening plastic there is no cross-linking.

Figure 14.8

Disposal of plastics

In the last 30 years plastics have taken over as replacement materials for metals, glass, paper and wood as well as for natural fibres such as cotton and wool. This is not surprising since plastics are light, cheap, relatively unreactive, can be easily moulded and can be dyed bright colours. However, this situation has contributed significantly to the household waste problem. Figure 14.9 shows some EU average figures for solid household waste.

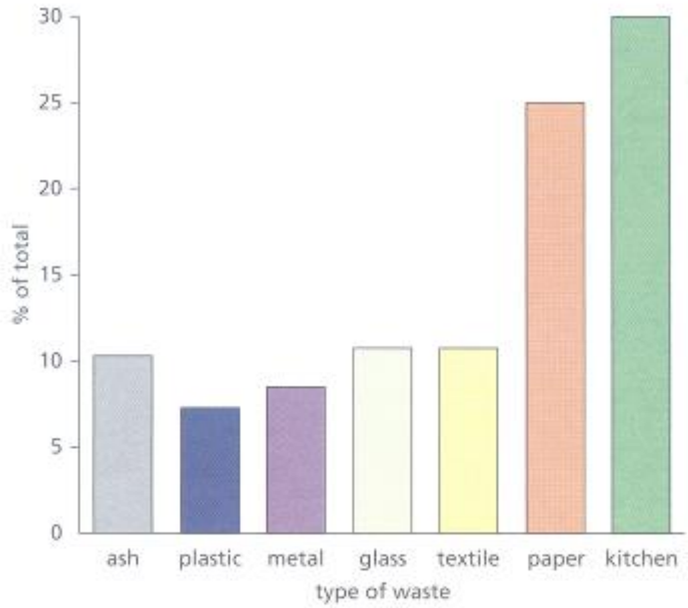


Figure 14.9 Amount of plastic waste compared with other household waste in EU countries.

In the recent past much of our plastic waste has been used to landfill disused quarries. However, these sites are getting harder to find and it is becoming more and more expensive. The alternatives to dumping plastic waste are certainly more economical and more satisfactory.

- Incineration — schemes have been developed to use the heat generated for heating purposes.

- Recycling — large quantities of black plastic bags and sheeting are produced for resale.

- Biodegradable plastics, as well as those polymers that degrade in sunlight (**photodegradable**, Figure 14.10a), have been developed. Other common categories of degradable plastics include synthetic biodegradable plastics which are broken down by bacteria, as well as plastics which dissolve in water (Figure 14.10b). The property that allows plastic to dissolve in water has been used in relatively new products, such as Ariel Liquitabs and Persil Capsules.

a This plastic bag is photodegradable.

b This plastic dissolves in water.

Figure 14.10

Questions

1. Write the general equation to represent the formation of polystyrene from its monomer.

2. Suggest other uses for the polymers shown in Table 14.1.

3. Draw the structure of the repeating units found in:

a. nylon
b. terylene.

4. Explain the differences between an addition polymer and a condensation polymer.

5. Give two advantages and two disadvantages of plastic waste (rubbish).

Some biopolymers

Starch is a **biopolymer** or **natural polymer**. It is a condensation polymer of glucose, a type of sugar. It is often produced as a way of storing energy and is formed as a result of photosynthesis in green plants.

$$\text{carbon dioxide + water} \xrightarrow[\text{sunlight/ chlorophyll (in green plants)}]{\text{photosynthesis}} \text{glucose + oxygen}$$

$$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$$

$$\text{glucose} \rightarrow \text{starch + water}$$

$$nC_6H_{12}O_6(aq) \rightarrow (C_6H_{10}O_5)_n(s) + nH_2O(l)$$

Both starch and glucose are **carbohydrates**, a class of naturally occurring organic compounds which can be represented by the general formula $(CH_2O)_x$. Starch occurs in potatoes, rice and wheat. Glucose, from which starch is polymerised, belongs to a group of simple carbohydrates known as **monosaccharides**. They are sweet to taste and soluble in water. Starch belongs to the more complicated group of carbohydrates known as **polysaccharides**. Starch does not form a true solution and it does not have a sweet taste. With iodine it gives an intense blue colour (nearly black), which is used as a test for starch or iodine itself.

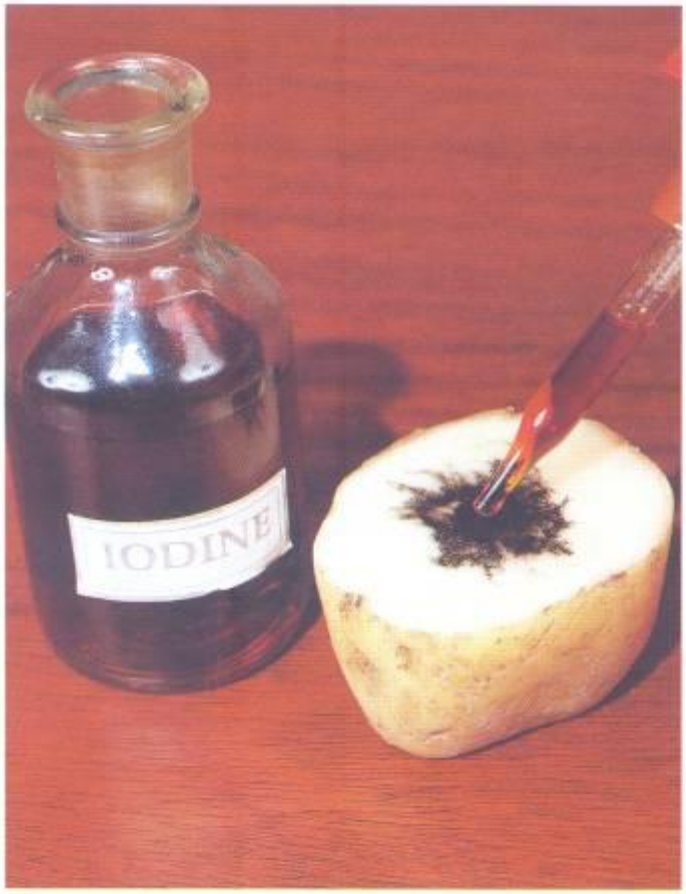


Figure 14.11 A dark blue-black colour is produced when dilute iodine solution is applied to starch, for example in a potato.

Hydrolysis of starch

Starch can be broken down in two ways, both of which take place in the presence of water. Hence the reactions are known as **hydrolysis** reactions. Hydrolysis of starch is the key reaction that enables us to use this energy source. If starch is boiled for about one hour with dilute hydrochloric acid, it is broken down into its monomers, glucose molecules.

$$\text{starch} + \text{water} \xrightarrow[\text{heat}]{\text{dilute acid}} \text{glucose}$$

$$(C_6H_{10}O_5)_n(s) + nH_2O(l) \rightarrow nC_6H_{12}O_6(aq)$$

If starch is mixed with saliva and left to stand for a few minutes, it will break down to maltose, a **disaccharide** (that is two joined monosaccharides).

The enzyme present in the saliva, called amylase, catalyses this hydrolysis reaction.

$$\text{starch + water in saliva} \xrightarrow{\text{amylase}} \text{maltose}$$

$$2(C_6H_{10}O_5)_n(s) + nH_2O(l) \rightarrow nC_6H_{12}O_6(aq)$$

Enzymes are very efficient natural catalysts present in plants and animals. They do not require high temperatures to break down the starch to maltose (Chapter 11). In humans, a salivary amylase breaks down the starch in our food. If you chew on a piece of bread for several minutes, you will notice a sweet taste in your mouth. The above hydrolysis reactions are summarised in Figure 14.12.

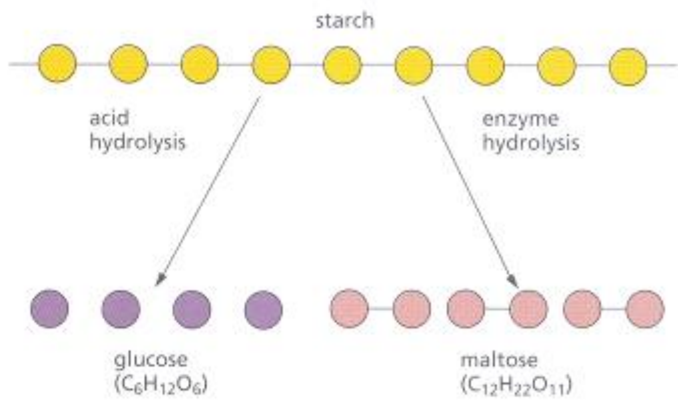


Figure 14.12 Starch produces glucose or maltose depending on the type of hydrolysis used.

Questions

1. In the hydrolysis of starch, how, using a chemical test, could you tell whether all the starch had been hydrolysed?

2. Describe a method you could possibly use to identify the products of the different types of hydrolysis.

Ethanol (C_2H_5OH) — an alcohol

The alcohols form another homologous series with the general formula $C_nH_{2n+1}OH$. All the alcohols possess an –OH as the **functional group**. The functional group is the group of atoms responsible for the characteristic reactions of a compound. Table 14.2 shows the first three members along with their melting and boiling points. Figure 14.13 shows the actual arrangement of the atoms in these first three members of this family.

Table 14.2 The first three members of the alcohol family.

Alcohol	**Formula**	**Melting point/°C**	**Boiling point/°C**
Methanol	CH_3OH	-94	64
Ethanol	CH_3CH_2OH	-117	78
Propanol	$CH_3CH_2CH_2OH$	-126	97

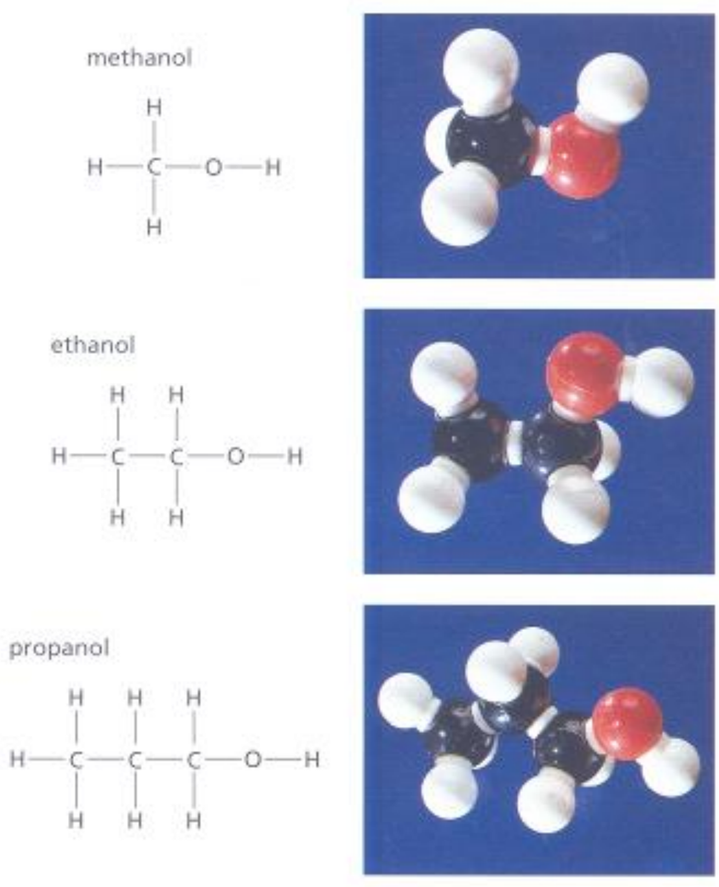


Figure 14.13 The molecules look like their corresponding models in the photographs.

Ethanol is by far the most important of the alcohols and is often just called 'alcohol'. Ethanol can be produced by fermentation as well as by the hydration of ethene (Chapter 12, p. 179). It is a neutral, colourless, volatile liquid which does not conduct electricity. Ethanol burns quite readily with a clean, hot flame.

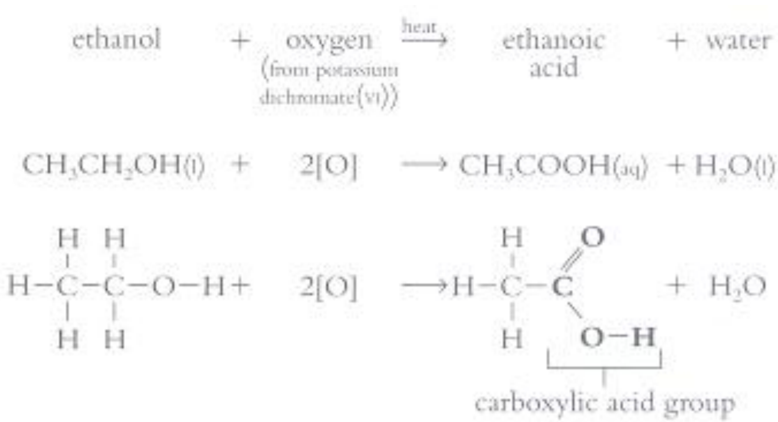
$$\text{ethanol} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$

$$CH_3CH_2OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g) + \text{energy}$$

As methylated spirit, or meths, it is used in spirit (camping) stoves. Methylated spirit is ethanol with small amounts of poisonous substances added to stop you drinking it. Also, some countries, like Brazil, are already using ethanol mixed with petrol as a fuel for cars (Chapter 13).

Many other materials, such as food flavourings, are made from ethanol. Ethanol is a very good solvent and evaporates easily. It is therefore used extensively as a solvent for paints, glues, aftershave and many other everyday products.

Ethanol can be oxidised to ethanoic acid (an organic acid also called acetic acid) by powerful oxidising agents, such as warm acidified potassium di-chromate (VI). During the reaction the orange colour of potassium dichromate (VI) changes to a dark green (Figure 14.14) as the ethanol is oxidised to ethanoic acid.



A similar oxidation process takes place, but more slowly, if wine or beer is left open. It will eventually turn to 'vinegar' (ethanoic acid) due to bacterial oxidation of the ethanol in the alcoholic drink.

Figure 14.14 Orange potassium dichromate(VI) slowly turns green as it oxidises ethanol to ethanoic acid.

Questions

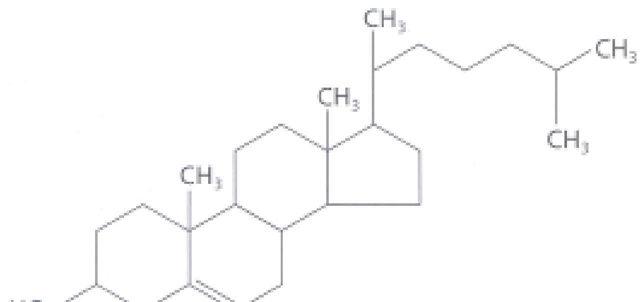
1. Write the structural formula for butanol.

2. Write a word and balanced chemical equation for:

a. the combustion of butanol
b. the oxidation of butanol.

Cholesterol — a steroid

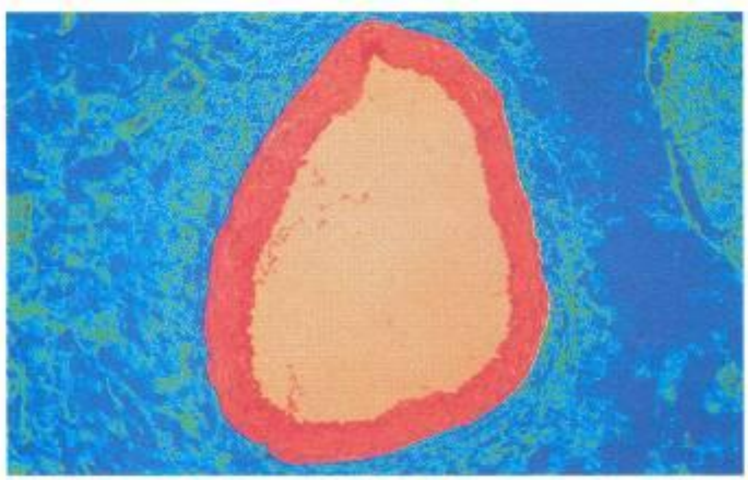
Cholesterol is a naturally occurring and essential chemical. It belongs to a family of chemicals called steroids and also contains an alcohol group (Figure 14.15). Cholesterol is found in almost all of the tissues in the body, including nerve cells. Levels of cholesterol above normal (above 6.5 mmol/l) are associated with an increased risk of heart disease. Cholesterol hardens and blocks off arteries by building up layers of solid material (atheroma) inside the arteries (Figure 14.16). This is particularly serious if the arteries that supply the heart or brain are blocked. Simple tests are now available to monitor cholesterol levels and people with high levels can be treated and can follow special low-fat and low-cholesterol diets.



cholesterol

Figure 14.15 The structure of cholesterol.

a This artery is being blocked by atheroma, which may be related to high levels of cholesterol in the blood.



b This is a healthy artery.

Figure 14.16

Biotechnology

Biotechnology involves making use of micro-organisms or their components, such as enzymes, for the benefit of humans to produce, for example, foods such as yoghurt and bread. One of the oldest bio-technologies is that of **fermentation**. It involves a series of biochemical reactions brought about by micro-organisms or enzymes. Fermentation is the basic process behind the baking, wine- and beer-making industries.

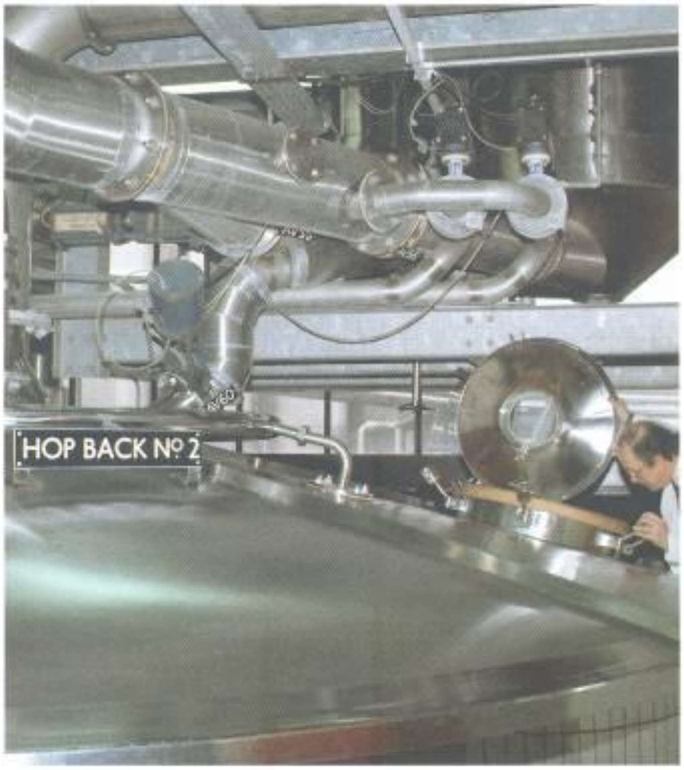
Fermentation in the laboratory can be carried out using sugar solution. A micro-organism called yeast is added to the solution. The yeast uses the sugar for energy during **anaerobic respiration** (respiration without oxygen), and so the sugar is broken down to give carbon dioxide and ethanol. The best temperature for this process to be carried out is at 37°C.

$$\text{glucose} \xrightarrow{\text{yeast}} \text{ethanol} + \text{carbon dioxide}$$

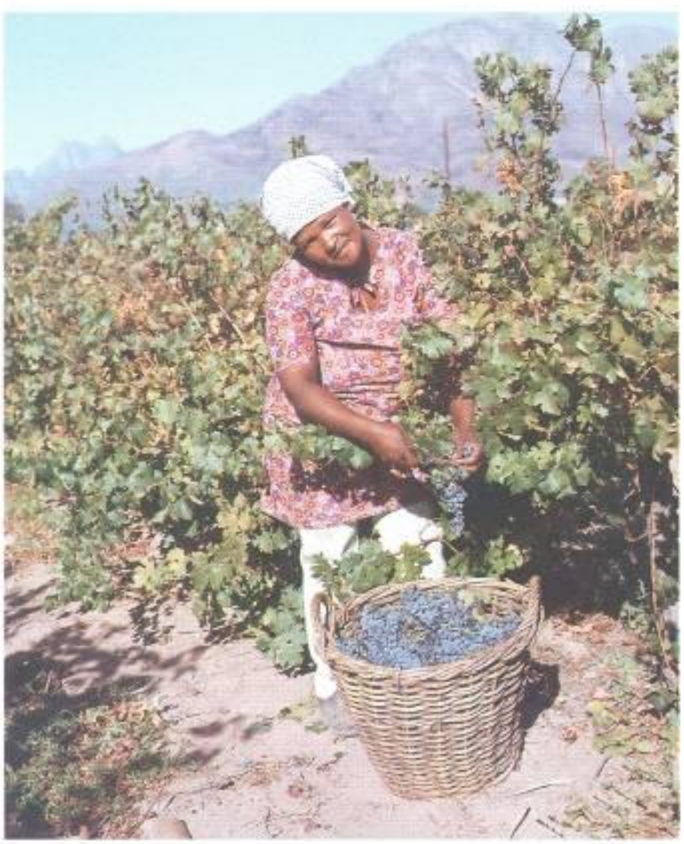
$$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(l) + 2CO_2(g)$$

Figure 14.17 shows a simple apparatus for obtaining ethanol from glucose in the laboratory.

Figure 14.17 Fermenting glucose and yeast to produce ethanol. The bag is inflated during the experiment by CO_2.



a Beer is produced on a large scale.



b Grape picking for the wine-making industry.

Figure 14.18

Alcoholic drinks such as beer and wine are made on a large scale in vast quantities. Beer is made from barley to which hops are added to produce the distinctive flavour (Figure 14.18a), whereas wine is made by fermenting grape juice, which contains glucose (Figure 14.18b). The micro-organisms in yeast will carry out the fermentation quite successfully in both cases. Beer normally contains only about 4% by volume of ethanol, whereas wine contains about 11%.

The yeast is killed off if there is much more ethanol than this, so it is not possible to make stronger drinks by fermentation. Some of the stronger drinks in Table 14.3, like sherry, are made up to 'strength' by adding pure ethanol.

Table 14.3 Ethanol content of different drinks.

Drink	Percentage ethanol by volume
Whisky, brandy	40
Sherry	20
Martini	14
Wine	11
Beer	4

Spirits such as whisky and brandy are more concentrated forms of alcoholic drink. These higher concentrations of ethanol are produced by distillation after the fermentation process is complete (Figure 14.19).

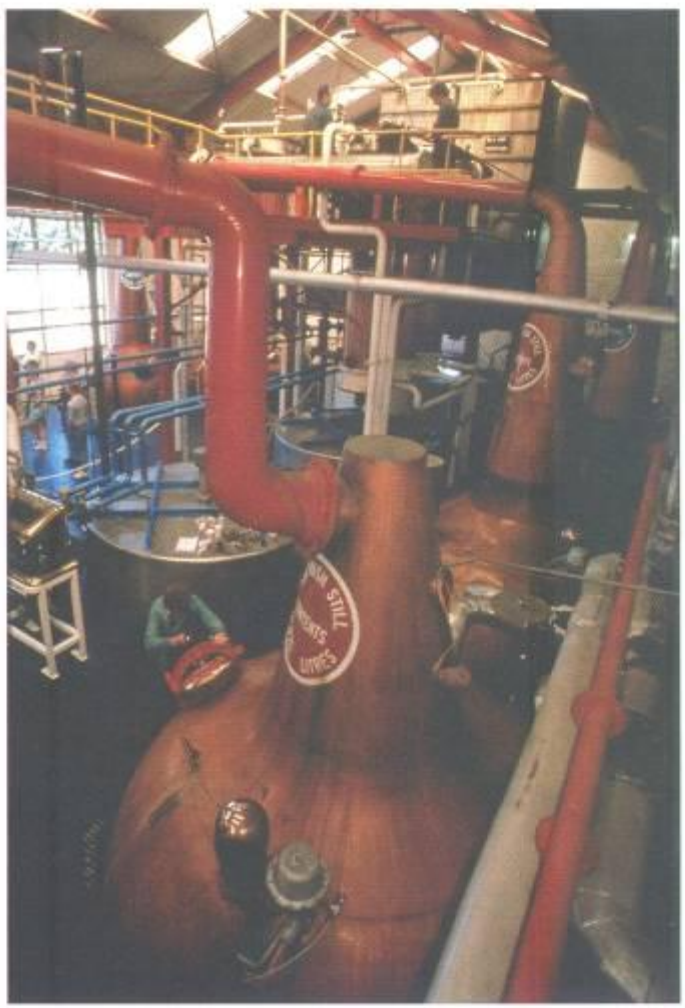


Figure 14.19 A whisky distillery.

Treat alcohol carefully

As you will know, it is the alcohol (ethanol) in these drinks that can make people drunk. It is also the alcohol which causes headaches (the 'hangover'), dizziness and vomiting associated with being drunk. Alcohol can damage vital organs in your body. Excessive intake over an extended period of time can cause irreparable damage to the liver (cirrhosis) and can result in death.

Figure 14.20 Because alcohol is readily available, it is easy for people to misuse it. Abusing alcohol is a serious problem in our society.

Alcohol is a drug and is addictive (Figure 14.20). There are about half a million alcoholics in the UK. Because of their addiction, alcoholics often have health, family and work problems.

Even small amounts of alcohol in the bloodstream can reduce your judgement and skill. Up to a third of all road accidents are associated with alcohol. The introduction of the breathalyser had a marked effect on road accident figures. In its first year of use there were 40000 fewer accidents on the roads of the UK. The 'Alcotest 80' breathalyser tubes contain potassium dichromate (VI) crystals (Figure 14.21). When you breathe into a breathalyser, if your exhaled air contains alcohol vapour some of the potassium dichromate (VI) crystals turn green. How far the green colour extends along the tube is a measure of the amount of alcohol in your breath. The extent of the green colour is taken as a measure of the blood alcohol concentration (BAC).

The legal limit on BAC is 80 mg of alcohol per 100 cm3 of blood. If you 'fail' on the 'Alcotest 80' breathalyser, a blood sample is taken to confirm the actual level of alcohol in your blood.

Table 14.4 shows the effects of different blood alcohol levels on an average person. It is important to appreciate that young people may experience these effects after less alcohol than the table shows.

Table 14.4 Effects of different blood alcohol levels.

Number of drinks	**Approximate BAC level**	**Effects**
1 pint of beer	30 mg	Increased chance of an accident
3 single whiskies	50 mg	Cheerful, judgement affected, less inhibited
5 single whiskies	80 mg	This is the legal limit for driving. You are four times more likely to have an accident

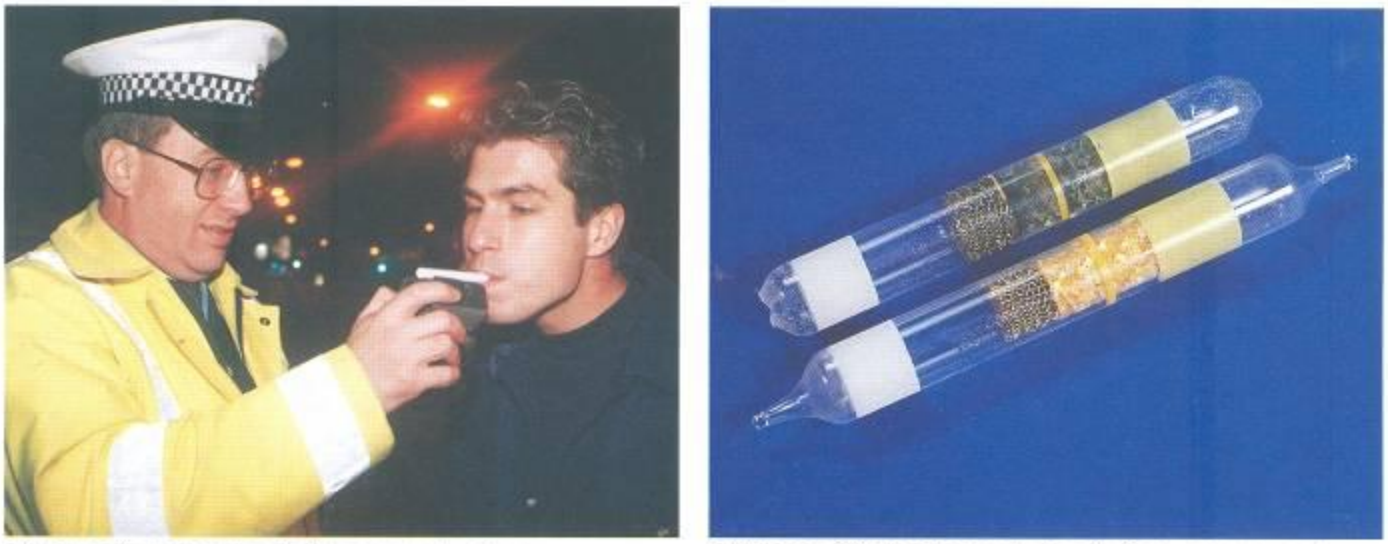
Baking

A **baker** is involved with biotechnology. To make bread, fresh yeast is mixed with warm sugar solution and the mixture added to the flour. This dough mixture is then put into a warm place to rise. The dough rises due to the production of carbon dioxide from **aerobic respiration** (respiration with oxygen) by the yeast. The products of this style of respiration are different to those of anaerobic respiration (see p. 204).

$$\text{sugar + oxygen} \xrightarrow{\text{yeast}} \text{carbon dioxide + water + energy}$$

$$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) + \text{energy}$$

After the dough has 'risen', it is baked and the heat kills the yeast and the bread stops rising.



a A driver's alcohol level being assessed using a breathalyser.

b 'Alcotest 80' breathalyser tubes (before, orange, and after, green).

Figure 14.21

New applications

A large number of firms throughout the world are investing large sums of money in the newer biotechnology applications now in use.

- Enzymes can be isolated from micro-organisms and used to catalyse reactions in other processes. For example, proteases are used in biological detergents to digest protein stains such as blood and food. Also, catalase is used in the rubber industry to help convert latex into foam rubber.

- Our ability to manipulate an organism's genes to make it useful to us is called **genetic engineering**. This is being used, for example, to develop novel plants for agriculture as well as making important human proteins such as the hormones insulin and growth hormone.

However, a word of caution is necessary. The new biotechnologies may not be without dangers. For ex-ample, new pathogens (organisms that cause disease) might be created accidentally. Also, new pathogens may be created deliberately for use in warfare. As you can imagine, there are very strict guidelines covering these new biotechnologies, especially in the area of research into genetic engineering.

Questions

1. What do you understand by the term 'biotechnology'? In your answer make reference to the making of beer and bread.

2. With reference to the data shown in Table 14.3, answer the following.

a. Calculate the amount of ethanol (alcohol) in 1 litre of whisky or brandy.

b. An advert for Campari suggested it contained 15% more alcohol by volume than sherry. Calculate the percentage by volume of alcohol in Campari and also calculate the amount of alcohol in a 1 litre bottle of Campari.

c. Low-alcohol beer contains about 0.5% of alcohol by volume. How many litres of this beer contain the same volume of alcohol as 2 litres of normal-strength beer?

Ethanoic acid (CH_3COOH) — a carboxylic acid

The carboxylic acids form another homologous series, this time with the general formula $C_nH_{2n-1}OOH$. All the carboxylic acids possess –COOH as their functional group. Table 14.5 shows the first three members of this homologous series along with their melting and boiling points. Figure 14.22 shows the actual arrangement of the atoms in these three members of this family.

Table 14.5 The first three members of the carboxylic acid series.

Carboxylic acid	Formula	Melting point/°C	Boiling point/°C
Methanoic acid	HCOOH	9	101
Ethanoic acid	CH_3COOH	17	118
Propanoic acid	CH_3CH_2COOH	-21	141

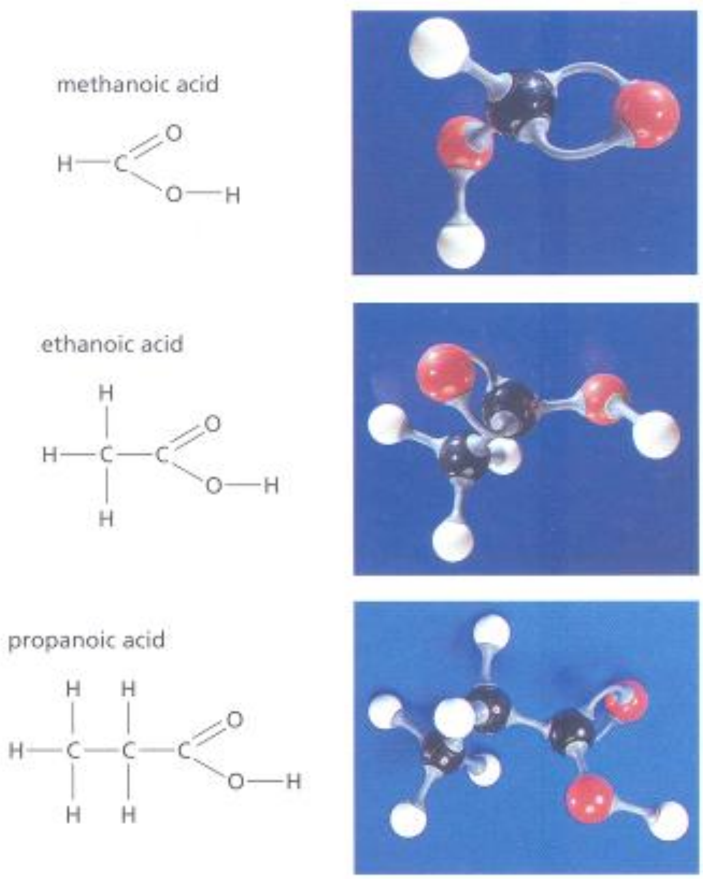


Figure 14.22 The molecules look like the 3D models in the photographs.

Methanoic acid is present in stinging nettles and ant stings. Ethanoic acid, however, is the most well known as it is the main constituent of vinegar. Like other acids, ethanoic acid affects indicators and will react with metals such as magnesium. However, whereas the mineral acids such as hydrochloric acid are called strong acids, ethanoic acid is a weak acid (Chapter 7. Even though it is a weak acid, it will still react with bases to form salts. For example, the salt sodium ethanoate is formed when ethanoic acid reacts with dilute sodium hydroxide.

$$\text{ethanoic acid + sodium hydroxide} \rightarrow \text{sodium ethanoate + water}$$

$$CH_3OOOH(aq) + NaOH(aq) \rightarrow CH_3OOONa(aq) + H_2O(l)$$

Ethanoic acid also undergoes other typical reactions of acids, in that it reacts with indicators, metals and carbonates in the usual way.

Ethanoic acid will react with ethanol, in the presence of a few drops of concentrated sulphuric acid, to produce ethyl ethanoate — an **ester**.

$$\text{ethanoic acid + ethanol} \xleftrightarrow[H_2SO_4]{\text{conc}} \text{ethyl ethanoate + water}$$

$$CH_3OOOH(l) + CH_3CH_2OH(l) \leftrightarrow CH_3OOOCH_2CH_3(aq) + H_2O(l)$$

This reaction is called **esterification**.

Members of the 'ester' family have strong and pleas-ant smells. Many of them occur naturally and are responsible for the flavours in fruits and the smells of flowers. They arc used, therefore, in some food flavourings and in perfumes (Figure 14.23).

Figure 14.23 Perfumes contain esters.

Fats and oils are naturally occurring esters which are used as energy storage compounds by plants and animals (Figure 14.24).

Figure 14.24 Olive oil is obtained from a plant whereas lard is made from animal fat.

Questions

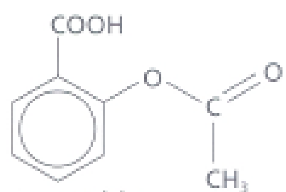
1. Write the structural formula for propanoic acid.

2. Write word and balanced chemical equations for the esterification of propanoic acid with ethanol.

Other carboxylic acids

Aspirin

Aspirin (Figure 14.25) is one of the most frequently used painkillers in the world. It is also able to reduce inflammation and fever and a low dose taken on a daily basis over the age of 50 may prevent heart attacks. It is derived from another acid, salicylic acid, which can be obtained from willow bark. Salicylic acid has the same medicinal properties as aspirin and has been known since 1829. Salicylic acid, however, caused stomach bleeding. The conversion of salicylic acid to aspirin reduced these problems, but aspirin still has some adverse effects on the stomach if taken in excess.

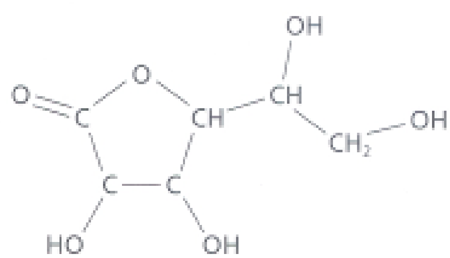


aspirin

Figure 14.25 The structure of aspirin.

Ascorbic acid (vitamin C)

Vitamin C, also known as ascorbic acid, is an essential vitamin (Figure 14.26). Vitamin C is required by the body in very small amounts and it is obtained from foods.



ascorbic acid

Figure 14.26 The structure of ascorbic acid (vitamin C).

Vitamin C is important to all animals, including humans, and is vital in the production of collagen. Collagen is important in the formation of connective tissues that give our body shape and help to support vital organs. Vitamin

C prevents the disease scurvy. It is found in citrus fruits and brightly coloured vegetables, such as peppers and broccoli. Many people take vitamin C supplements, which are readily available from supermarkets and pharmacies (Figure 14.27). Although vitamin C is destroyed by exposure to air and heat, the average person usually reaches the recommended daily allowance of 60 mg through food.

Figure 14.27 These fruits and supplements all contain vitamin C.

Citric acid

Citric acid is an example of a tricarboxylic acid, one which contains three COOH groups (Figure 14.28). It is an important acid and is found in all citrus fruits, for example lemons and oranges.

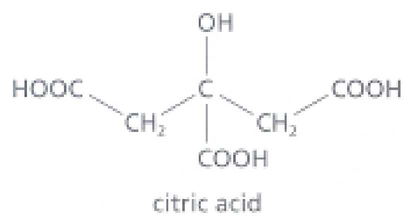


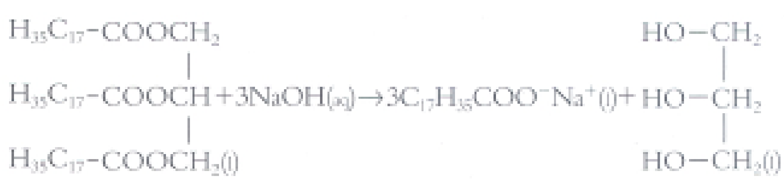
Figure 14.28 The structure of citric acid.

Soaps and detergents

Millions of tonnes of soaps and soapless detergents are manufactured worldwide every year. Soap is manufactured by heating natural fats and oils of either plants or animals with a strong alkali. These fats and oils, called triglycerides, are complicated ester molecules.

Fat is boiled with aqueous sodium hydroxide to form soap. The esters are broken down in the presence of water – hydrolysed. This type of reaction is called **saponification**. The equation given below is that for the saponification of glyceryl stearate (a fat).

glyceryl stearate + sodium hydroxide → sodium stearate (soap) + glycerol



The cleaning properties of the soap depend on its structure and bonding. Sodium stearate consists of a long hydrocarbon chain which is hydrophobic (water hating) attached to an ionic 'head' which is hydrophilic (water loving) (Figure 14.29).

Figure 14.29 Simplified diagram of a soap molecule.

Covalent compounds are generally insoluble in water but they are more soluble in organic solvents. Ionic compounds are generally water soluble but tend to be insoluble in organic solvents. When a soap is put into water which has a greasy dish (or a greasy cloth) in it, the hydrophobic hydrocarbon chain on each soap molecule becomes attracted to the grease

and becomes embedded in it (Figure 14.30).

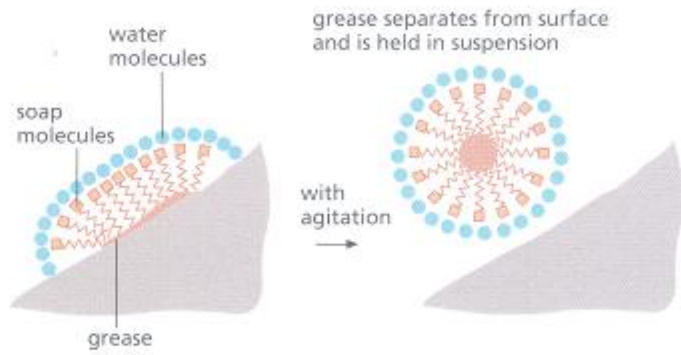


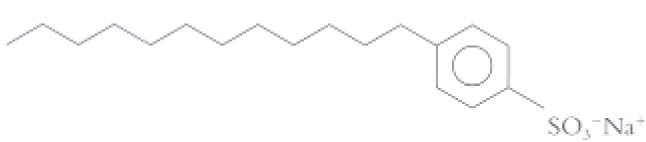
Figure 14.30 Soap dissolves grease like this.

On the other hand, the hydrophilic ionic head group is not attracted to the grease but is strongly attracted to the water molecules. When the water is stirred, the grease is slowly released and is completely surrounded by the soap molecules. The grease is, therefore, 'solubilised' and removed from the dish. The soap is able to remove the grease because of the combination of the covalent and ionic bonds present.

Soapless detergents

In Chapter 8, we discussed the way in which, in hard water areas, an insoluble scum forms when soap is used. This problem has been overcome by the development of synthetic **soapless detergents**. These new substances do not form scum with hard water since they do not react with Ca^{2+} and Mg^{2+} present in such water. Furthermore, these new soapless detergent molecules have been designed so that they are biodegradable. Bacteria readily break down these new molecules so that they do not persist in the environment.

Sodium alkyl benzene sulphonates were developed in the early 1970s. The structure of sodium 3-dodecylbenzene sulphate, $C_{18}H_{29}SO_3Na$, is given below.



The calcium and magnesium salts of this detergent molecule are water soluble, so the problem of scum is solved. Very many of our washing powders (and liquids) contain this type of substance. The manufacture of soapless detergents is explained in Chapter 16.

Questions

1. What class of organic compound do substances like glyceryl stearate belong to?

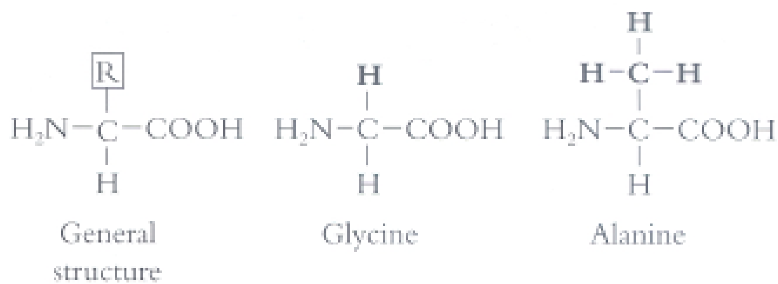
2. What do you understand by the terms:

a. hydrophobic?
b. hydrophilic?
c. saponification?

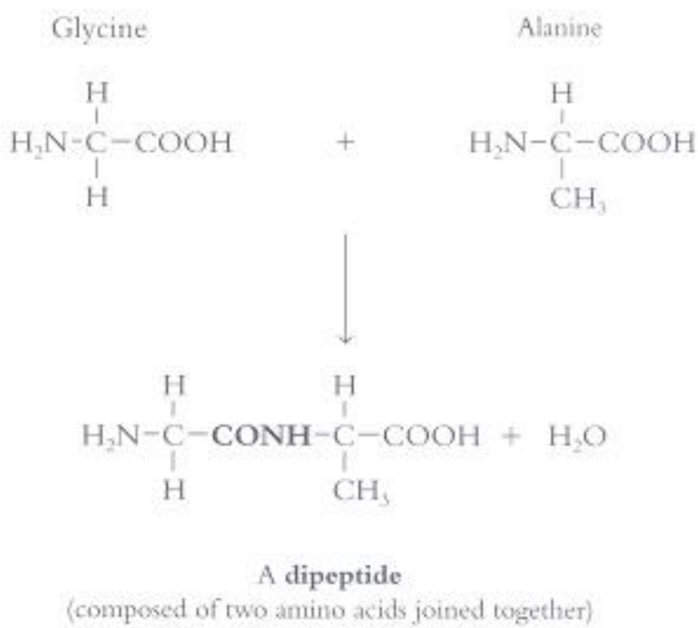
3. What is the main advantage of detergents over soaps?

Amino acids

There are 20 different amino acids and they each possess two functional groups. One is the carboxylic acid group, –COOH. The other is the amine group, $–NH_2$. The two amino acids shown below are glycine and alanine.



Amino acids are the building blocks of proteins. Similar to nylon (see p. 199) proteins are polyamides, as they contain the –CONH– group, which is called the amide or, in the case of proteins, the peptide link. Proteins are formed by condensation polymerisation.



Further reaction with many more amino acids takes place at opposite ends of each molecule to produce the final protein (Figure 14.31). For a molecule to be a protein, there must be at least 100 amino acids involved. Below this number, they are called polypeptides. Proteins make up some 15% of our

body weight.

Proteins fall broadly into two groups: they can be fibrous or globular.

- Fibrous proteins these have linear molecules, are insoluble in water and resistant to alkalis and acids. Collagen (in tendons and muscles), keratin (in nails, hair, horn and feathers) and elastin (in arteries) are all fibrous proteins.

- Globular proteins – these have complicated three-dimensional structures and are soluble in water. They are easily affected by acids, alkalis and temperature increase, when they are said to be denatured. Casein (in milk), albumen (in egg white) and enzymes are examples of globular proteins.

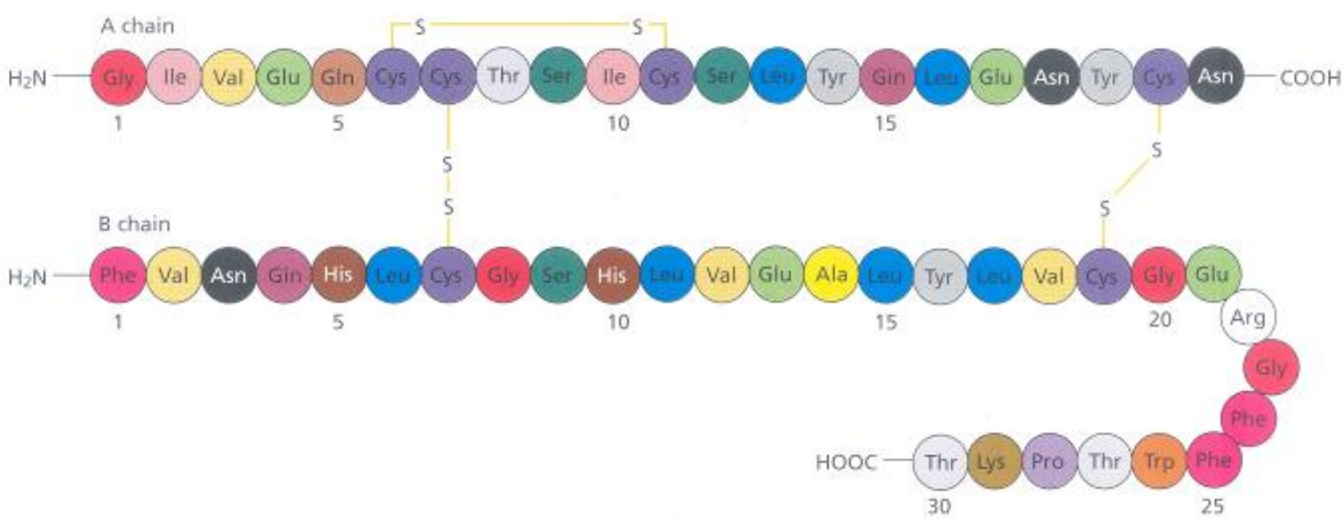


Figure 14.31 The structure of a protein – human insulin (the different coloured circles represent different amino acids in this protein).

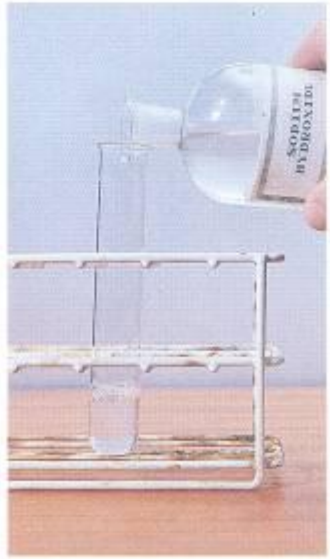
Protein analysis

How can you determine which amino acids are present in a particular protein? This involves hydrolysis of the peptide (amide) bonds in the protein so that the individual amino acids are released. This can only be done by heating the protein with dilute hydrochloric acid. The mixture of amino acids is then separated by thin layer chromatography (TLC) (Figure 14.32) or electrophoresis. In both cases, a locating agent (Chapter 2), such as ninhydrin, is used. This ensures that the spots of acid are visible.

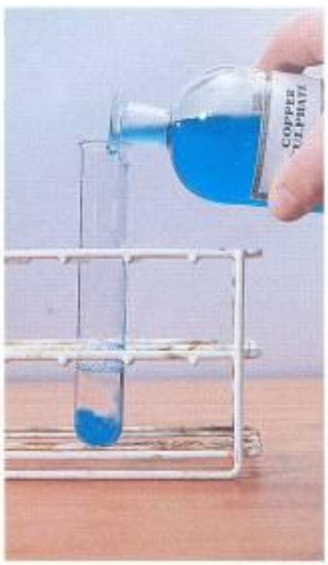
Figure 14.32 Amino acids can be separated and identified by TLC.

If you are trying to show only the presence of a protein, a quick test to carry out is known as the **Biuret test**. A mixture of dilute sodium hydroxide and 1% copper (II) sulphate solution is shaken with a sample of the material under test. If a protein is present, a purple colour appears after about three minutes (Figure 14.33).

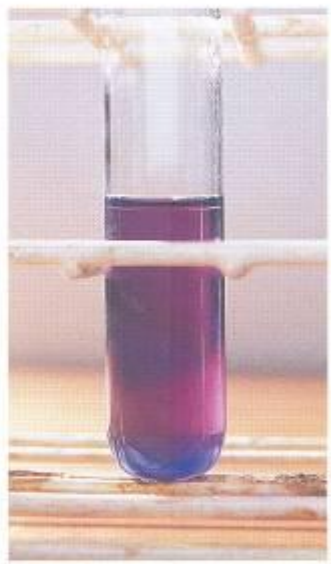
a Testing for a protein.



b Adding dilute sodium hydroxide.



c Adding 1% copper(II) sulphate.



d The purple colour shows the presence of a protein.

Figure 14.33

DNA

Deoxyribonucleic acid (DNA) belongs to a group of chemicals called the nucleic acids (Figure 14.34). They are also biopolymers. DNA controls the protein synthesis within your cells. When you eat a food containing proteins, such as meat or cheese, your digestive enzymes break down the proteins present into individual amino acids. The DNA in your cells controls the order in which the amino acids are repolymerised to make the proteins you need!

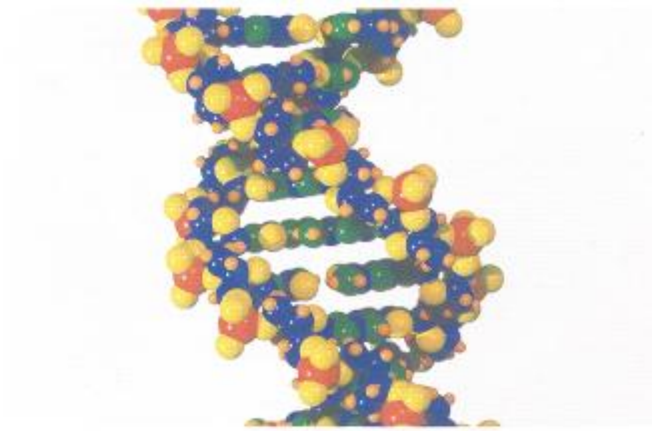


Figure 14.34 Crick and Watson based this model for DNA on X-ray studies and chemical analysis.

Genes are the units of heredity that control the characteristics of organisms. A gene is made of DNA. No two individuals have the same DNA sequence. DNA 'fingerprinting' has become a very powerful forensic science tool in the investigation of crime (Figure 14.35).

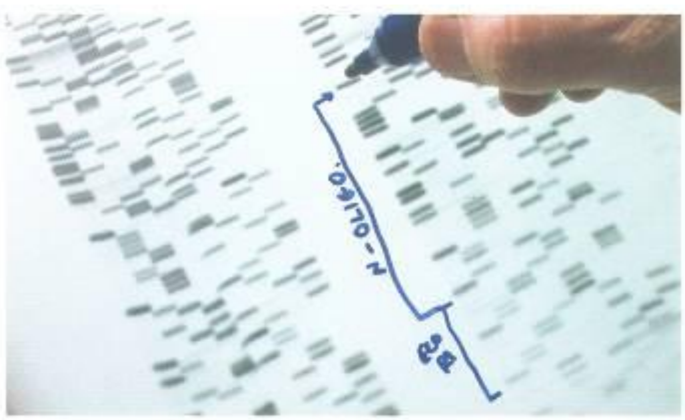


Figure 14.35 Identical patterns shown by DNA fingerprinting can identify the criminal.

Questions

1. Which two functional groups do amino acids possess?

2. How many amino acids have to be involved before the biopolymer is called a protein?

3. Name the process by which the individual amino acids in a protein are released by reaction with a dilute acid.

4. Explain how DNA fingerprinting may be used in paternity suits.

Pharmaceuticals

Pharmaceuticals are chemicals called **drugs** that are prepared and sold with the intention of treating illness. A drug is any substance, natural or synthetic, which alters the way in which the body works. There are many categories of drugs. The following are some examples.

- Anaesthetics – these induce loss of feeling and/or consciousness, for example flurothane.

- Analgesics – these relieve pain, for example aspirin.

- Antibiotics – these are substances, for example penicillin, originally produced by micro-organisms, which are used to kill bacteria. However, most antibiotics are now made in chemical laboratories, for example carbenicillin.

- Sedatives – these induce sleep, for example barbiturates.

- Tranquillisers – these will give relief from anxiety, for example Valium.

There are, of course, many other types of drug avail-able which have very specific uses. For example, methyldopa was developed to relieve hypertension (high blood pressure), and antihistamines were developed to help control travel sickness, hayfever and allergic reactions.

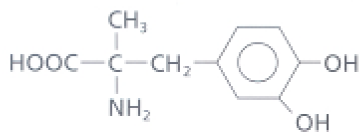
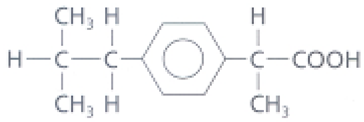
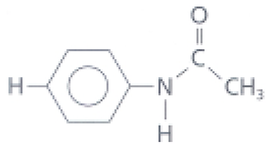
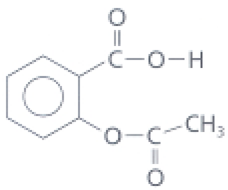
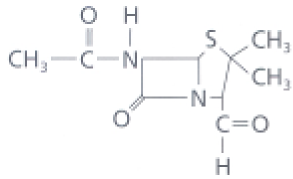
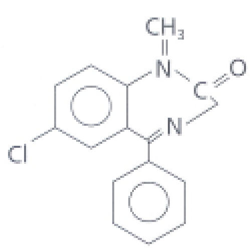
The pharmaceutical industry is one of the most important parts of the chemical industry and is a major consumer of the products of the petrochemical industry. It is a high-profit industry but with very high research and development costs. For example, it costs in excess of £100 million to discover, test and get a single drug on to the market.

Today, the pharmaceutical industry could be called the 'medicines by design' industry. Companies such as GlaxoSmithKline have teams of chemists and biochemists working almost around the clock to discover, test, check for safety and produce drugs that can deal with almost every known illness.

Table 14.6 (opposite) shows the structures of a selection of some of the

more common drugs available at the present time, along with their uses. The common names for these drugs are used, since their systematic, theoretical names are extremely complex.

Table 14.6 Commonly available drugs.

Name and structure	**For the treatment of**
	Headaches, mild pain, heart disease
	Headaches, mild pain
	Arthritis, fever, mild to moderate pain
	High blood pressure (hypertension)
	A variety of bacterial infections
	Feelings of anxiety or depression

Drug abuse

Some of the very useful drugs developed by chemists can be habit forming. For example, barbiturates (in sleeping tablets) and amphetamines (stimulants) fall into this category. Another drug that has created problems in the past is Valium, which is not itself addictive but when used in the long term makes people dependent on it. Severe psychological and physiological problems can arise.

It should be noted, however, that it is the opiates which cause **addiction** (Figure 14.36). Cocaine and heroin are just two examples of such substances. Consequences of the addiction include personal neglect, both of nutritional needs and of hygiene. For a short-term feeling of well-being ('fix'), the addict is prepared to do almost anything. Addicts often turn to a life of crime to fulfill their cravings for the opiates. Addicts, especially those injecting drugs, are at a high risk of HIV (human immunodeficiency virus) infection as they often share needles with other drug addicts, who may be HIV positive. Public awareness campaigns aim to educate everyone on the dangers in society, including drug abuse and its related risks.

Figure 14.36 Increasing public awareness of the risks associated with drug abuse is very important.

Questions

1. Using the data given in Table 14.6, suggest which of the pharmaceuticals contains:

a. sulphur
b. an –OH group
c. an $–NH_2$ group
d. an ester group.

2. Drug abuse is a rapidly growing problem. Using the information given in this section as well as your research skills, make a list of the addictive drugs. Also explain the problems that drug abuse can cause.

Checklist

After studying Chapter 14 you should know and understand the following terms.

Addition polymer A polymer formed by an addition reaction. For example, polythene is formed from ethene.

Alcohols Organic compounds containing the –OH group. They have the general formula $C_nH_{2n+1}OH$. Ethanol is by far the most important of the alcohols and is often just called 'alcohol'.

Amino acids These naturally occurring organic compounds possess both an $–NH_2$ group and a –COOH group on adjacent carbon atoms. There are 20 naturally occurring amino acids, of which glycine is the simplest.

Biodegradable plastics Plastics designed to degrade (decompose) under the influence of bacteria.

Biopolymers Natural polymers such as starch and proteins.

Biotechnology Making use of micro-organisms in industrial and commercial processes. For example, the process of fermentation is brought about by the enzymes in yeast.

Biuret test The test for proteins. A mixture of dilute sodium hydroxide and 1% copper (II) sulphate solution is shaken with the material under test. A purple colour appears after about three minutes if a protein is present.

Carbohydrates A group of naturally occurring organic compounds which can be represented by the general formula $(CH_2O)_x$.

Carboxylic acids A family of organic compounds containing the functional group –COOH. They have the general formula $C_nH_{2n-1}COOH$. The most important and well known of these acids is ethanoic acid, which is the main constituent in vinegar. Ethanoic acid is produced by the oxidation of ethanol.

Condensation polymer A polymer formed by a condensation reaction (one in which water is given out). For example, nylon is produced by the

condensation reaction between 1,6-diaminohexane and hexanedioic acid.

Cross-linking The formation of side covalent bonds linking different polymer chains and therefore increasing the rigidity of, say, a plastic. Thermosetting plastics are usually heavily cross-linked.

DNA Abbreviation for deoxyribonucleic acid. It belongs to a group of biopolymers called the nucleic acids. It is involved in the polymerisation of amino acids in a specific order to form the particular protein required by a cell.

Drug Any substance, natural or synthetic, that alters the way in which the body works.

Drug abuse This term usually applies to the misuse of addictive drugs, which include barbiturates and amphetamines, as well as the opiates, cocaine and heroin. These drugs create severe psychological and physiological problems through self-indulgence. This leads to a variety of personal problems for the user.

Esters A family of organic compounds formed by the reaction of an alcohol with a carboxylic acid in the presence of concentrated H_2SO_4. This type of reaction is known as esterification. Esters are characterised by a strong and pleasant smell (many occur in nature and account for the smell of flowers).

Functional group The atom or group of atoms responsible for the characteristic reactions of a compound.

HIV Short for human immunodeficiency virus, from which AIDS (acquired immunodeficiency syndrome) can develop.

Hydrolysis A chemical reaction involving the reaction of a compound with water. Acid hydrolysis usually involves dilute hydrochloric acid, and enzyme hydrolysis involves enzymes such as amylase.

Monomer A simple molecule, such as ethene, which can be polymerised.

Monosaccharides A group of simple carbohydrates. They are sweet to taste and are water soluble (for example glucose).

Pharmaceuticals These are chemicals called drugs that are prepared and sold with the intention of treating disease (for example methyldopa).

Photodegradable plastics Plastics designed to degrade under the influence of sunlight.

Polymer A substance possessing very large molecules consisting of repeated units or monomers. Polymers therefore have a very large relative molecular mass.

Polymerisation The chemical reaction in which molecules (monomers) join together to form a polymer.

Polysaccharides A group of more complicated carbohydrates. They generally do not form true solutions and do not have a sweet taste (for example starch).

Proteins Polymers of amino acids formed by condensation reactions. They fall broadly into the two categories: fibrous proteins (for example keratin and collagen) and globular proteins (for example casein and albumen).

Soapless detergents These are soap-like molecules which do not form a scum with hard water. These substances have been developed from petrochemicals. Their calcium and magnesium salts are water soluble and they are biodegradable.

Soaps Substances formed by saponification. In this reaction, the oil or fat (glyceryl ester) is hydrolysed by aqueous sodium hydroxide to produce the sodium salt of the fatty acid, particularly sodium stearate (from stearic acid). Soap will dissolve grease because of the dual nature of the soap molecule. It has a hydrophobic part (the hydrocarbon chain) and a hydrophilic part (the ionic head) and so will involve itself with both grease and water molecules. However, it forms a scum with hard water by reacting with the Ca^{2+} (or Mg^{2+}) present.

Thermoplastics Plastics which soften when heated (for example polythene, PVC).

Thermosetting plastics Plastics which do not soften on heating but only

char and decompose (for example melamine).

The (wider) organic manufacturing industry

Additional questions

1. Explain the following.

a. The problem of plastic waste has been overcome.

b. The majority of detergents produced today are biodegradable.

c. In bread making, yeast is added to the mix and the dough left to stand for a period of time.

d. When wine is left open it eventually turns to vinegar.

e. Polythene is a thermoplastic.

2a. A detergent molecule may be represented by the following simplified diagram.

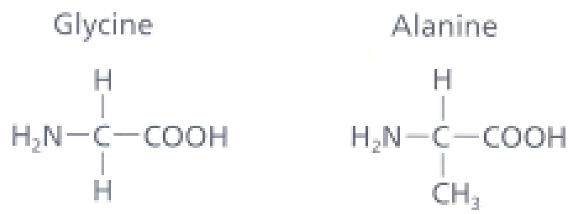
Use this representation of a detergent molecule in a series of labelled diagrams to show how detergents can remove grease from a piece of greasy cloth.

b. Explain why detergents do not form a scum with hard water, whereas soaps do.

c. The modern detergents are biodegradable.

(i) Explain what this statement means.
(ii) Why is it necessary for detergents to be biodegradable?

3. A piece of cheese contains protein. Proteins are natural polymers made up of amino acids. There are 20 naturally occurring amino acids. The structures of two amino acids are shown below.



a. Name the type of polymerisation involved in protein formation.

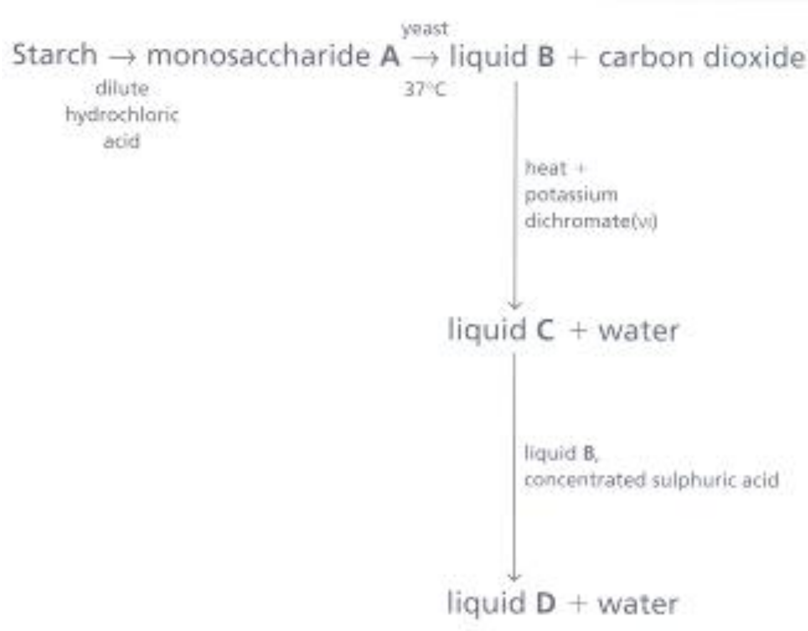
b. Draw a structural formula to represent the part of the protein chain formed by the reaction between the amino acids shown above.

c. What is the name given to the common linkage present in protein molecules?

d. Why is there such a huge variety of proteins?

e. Name and describe the features of the two broad groups of proteins.

4



a. Name, give the formula and one use of each of the substances A to D.

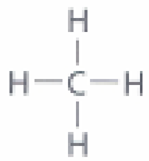
b. Write word and balanced chemical equations for the reactions involved in the formation of liquids B, C and D.

c. Starch is classified as a natural polymer or 'biopolymer'. Explain the meaning of this statement.

d. Name the processes by which:

(i) starch is broken down
(ii) liquid B is formed
(iii) liquid C is formed
(iv) liquid D is formed.

5a. Copy the following table and complete it by writing the structural formulae for methanol and methanoic acid.

Methane	Methanol	Methanoic acid
		

b. Describe a simple chemical test that could be used to distinguish methanol from methanoic acid.

c. (i) Name the class of compound produced when methanol reacts with methanoic acid.

(ii) Name the type of reaction taking place.

(iii) Write a word and balanced chemical equation for this reaction.

(iv) Give two uses related to the class of compound formed in this reaction.

d. The following reaction takes place when methanol is burned:

$$2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g) \qquad \Delta H = -1452 \text{ kJ mol}^{-1}$$

(i) How much heat energy would be liberated by burning:

0.5 mol of methanol?
4.0 mol of methanol?
4 g of methanol?

(ii) Calculate the volume of carbon dioxide produced at room temperature and pressure (rtp) when 16 g of methanol are burned.

(A_r: H = 1; C = 12; O = 16. One mole of any gas at rtp occupies 24 dm^3.)

6 This question requires you to use the information in Table 14.6.

a. Which grouping of atoms is common to all three painkillers?

b. Which of the pharmaceuticals contains:

(i) sulphur?
(ii) the greatest number of nitrogen atoms?
(iii) the carboxylic acid functional group?
(iv) chlorine?
(v) the greatest number of –CH3 groups?

c. Which of the pharmaceuticals is used to combat:

(i) bacterial infections?
(ii) depression?
(iii) heart disease?

d. The pharmaceuticals industry has often been termed the 'medicines by design' industry. Explain the meaning of this statement.

7. When a bottle of wine is left open to the air it turns sour. This is due to the oxidation, by the oxygen in the air, of the ethanol in the wine to ethanoic acid.

a. Write an equation to represent this oxidation process.

b. What would you expect to happen to the pH of the wine over a number of days?

c. Devise a method which would allow you to calculate the amount of ethanoic acid in the wine.

8. Why is it safe for us to use vinegar, which contains ethanoic acid, on food while it would be extremely dangerous for us to use dilute nitric acid for the same purpose?